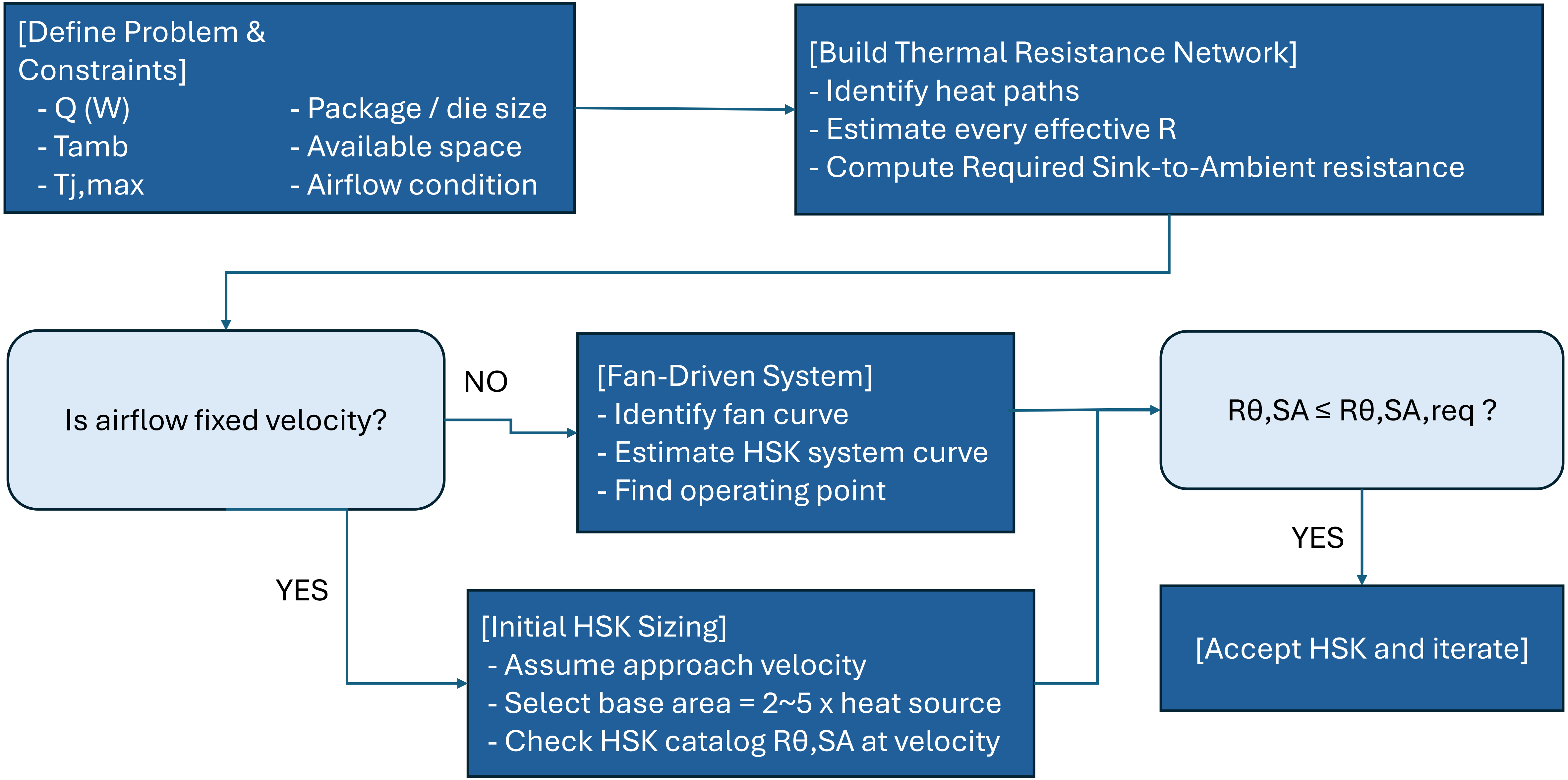
Thermal Design and Heat Sink Selection

Heat Sink Selection Workflow



Given Conditions and Thermal Resistance Model

T_ambient = 45 °C
T_junction = 70 °C

Heat Sink:
- Base Area = 6 cm x 6 cm
- Material = Aluminum

Grease:
- Area = 2 cm × 2 cm; thickness = 0.2 mm
- k = 1.5 W/mK

Package:
- Area = 2 cm × 2 cm; thickness = 5 mm
- k = 0.8 W/mK

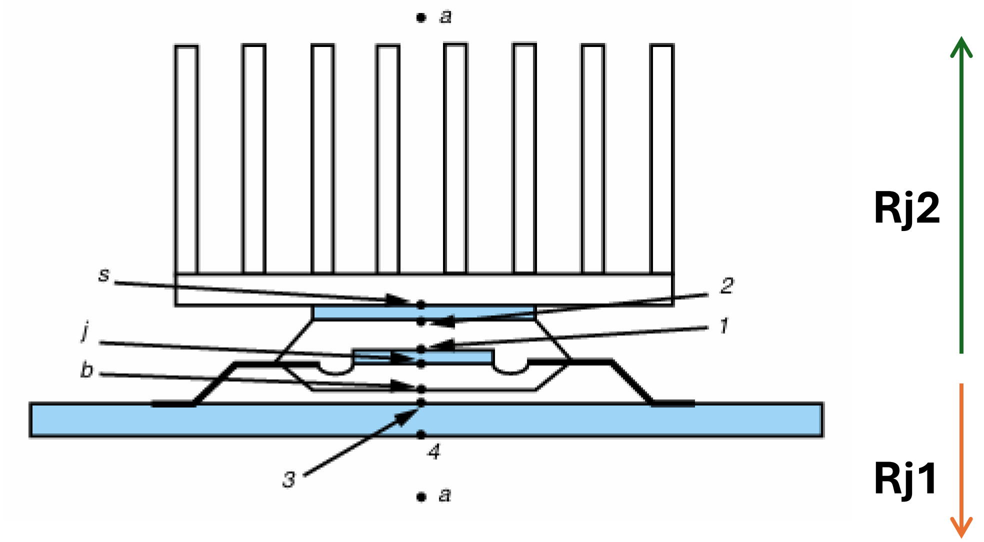
Die:
- Area = 1 cm × 1 cm; thickness = 1 mm
- Q = 2 W

Air Gap:
- Thickness = 0.1 mm

PWB:
- A copper plane and two layers of FR4
- Each layer thickness = 1 mm

PWB to Air:
- R = 10 K/W

$$\boldsymbol{R_{j2}} = R_{SA} + R_{grease} + R_{package\ mold} + R_{die}$$



$$\boldsymbol{R_{j1}} = R_{die} + R_{package\ mold} + R_{air\ \ gap} + R_{PWB} + R_{PWB2Air}$$

Analytical Estimation of Thermal Resistances

$\boldsymbol{R_{die} = 0.0833\ K/W}$

$$R_{j1} = \left.\frac{L}{kA}\right|_{\text{silicon}} = \frac{0.001}{120 \times 0.01 \times 0.01} = 0.08333\ \text{K/W}$$

$\boldsymbol{R_{package\ mold} = 10\ K/W}$

$$R_{12} = R_{jb} = \left.\frac{L}{kA}\right|_{\text{mold}} = \frac{0.002}{0.8 \times ((0.02^2 + 0.01^2)/2)} = 10\ \text{K/W}$$

$\boldsymbol{R_{grease} = 0.33\ K/W}$

$$R_{2s} = \left.\frac{L}{kA}\right|_{\text{grease}} = \frac{0.0002}{1.5 \times 0.02 \times 0.02} = 0.3333\ \text{K/W}$$

$\boldsymbol{R_{air\ gap} = 9.62\ K/W}$

$$R_{b3} = \left.\frac{L}{kA}\right|_{\text{air}} = \frac{0.0001}{0.026 \times 0.02 \times 0.02} = 9.62\ \text{K/W}$$

$\boldsymbol{R_{PWB} = 6.663\ K/W}$

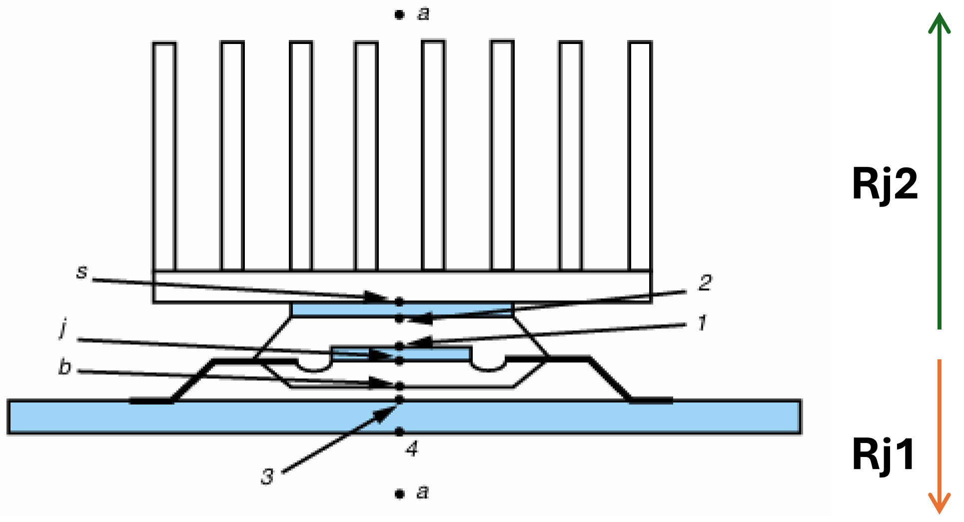
$$R_1 = \frac{L_1}{k_1A_1} = \frac{0.001}{0.3 \times 0.001} = 3.33\ \text{K/W}$$

$$R_2 = \frac{L_2}{k_2A_2} = \frac{0.001}{390 \times 0.001} = 0.00256\ \text{K/W}$$

$$R_{34} = R_1 + R_2 + R_3 = 3.33 + 0.0026 + 3.33 = 6.663\ \text{K/W}$$

$\boldsymbol{R_{PWB2Air} = 10\ K/W}$

$$\boldsymbol{R_{j2}} = R_{SA} + R_{grease} + R_{package\ mold} + R_{die} = R_{SA} + 10.42$$



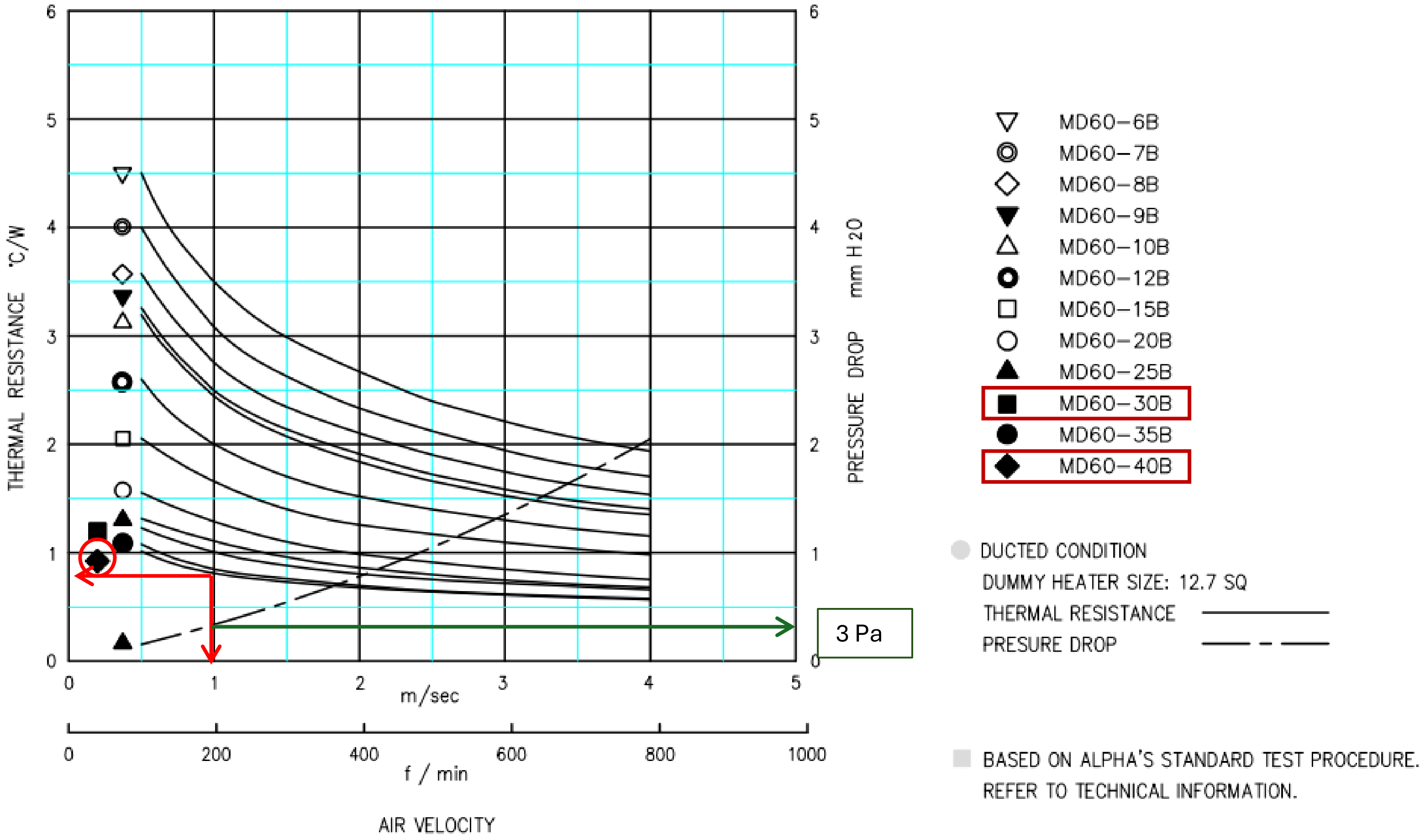
$$\boldsymbol{R_{j1}} = R_{package\ mold} + R_{air\ gap} + R_{PWB} + R_{PWB2Air} = 36.25$$

$$\begin{cases} R_{j2} = (T_j - T_a)/Q_2 = (62.3 - 45) \div Q_2 \\ R_{j1} = (T_j - T_a)/Q_1 = (62.3 - 45) \div Q_1 \\ Q_2 : Q_1 = R_{j1} : R_{j2} \end{cases}$$

As a conservative assumption, the **entire 2 W** of heat dissipation is assumed to be conducted through the heatsink. Therefore, the required sink-to-ambient thermal resistance, RSA, must be **less than 1.08 K/W.**

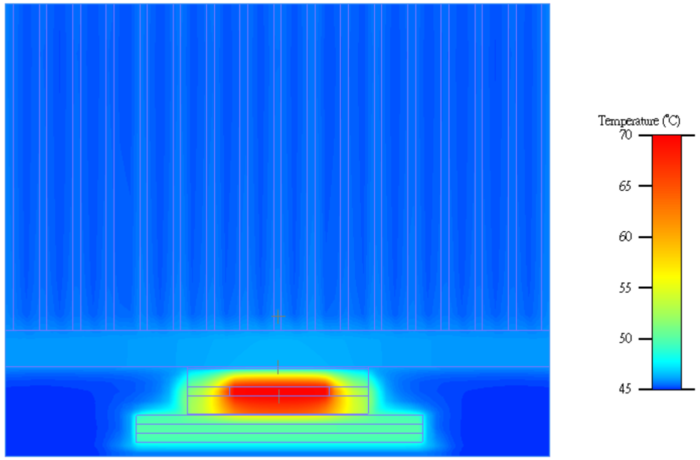
Case 1 — Airflow Given (Fixed Velocity / LFM Known)

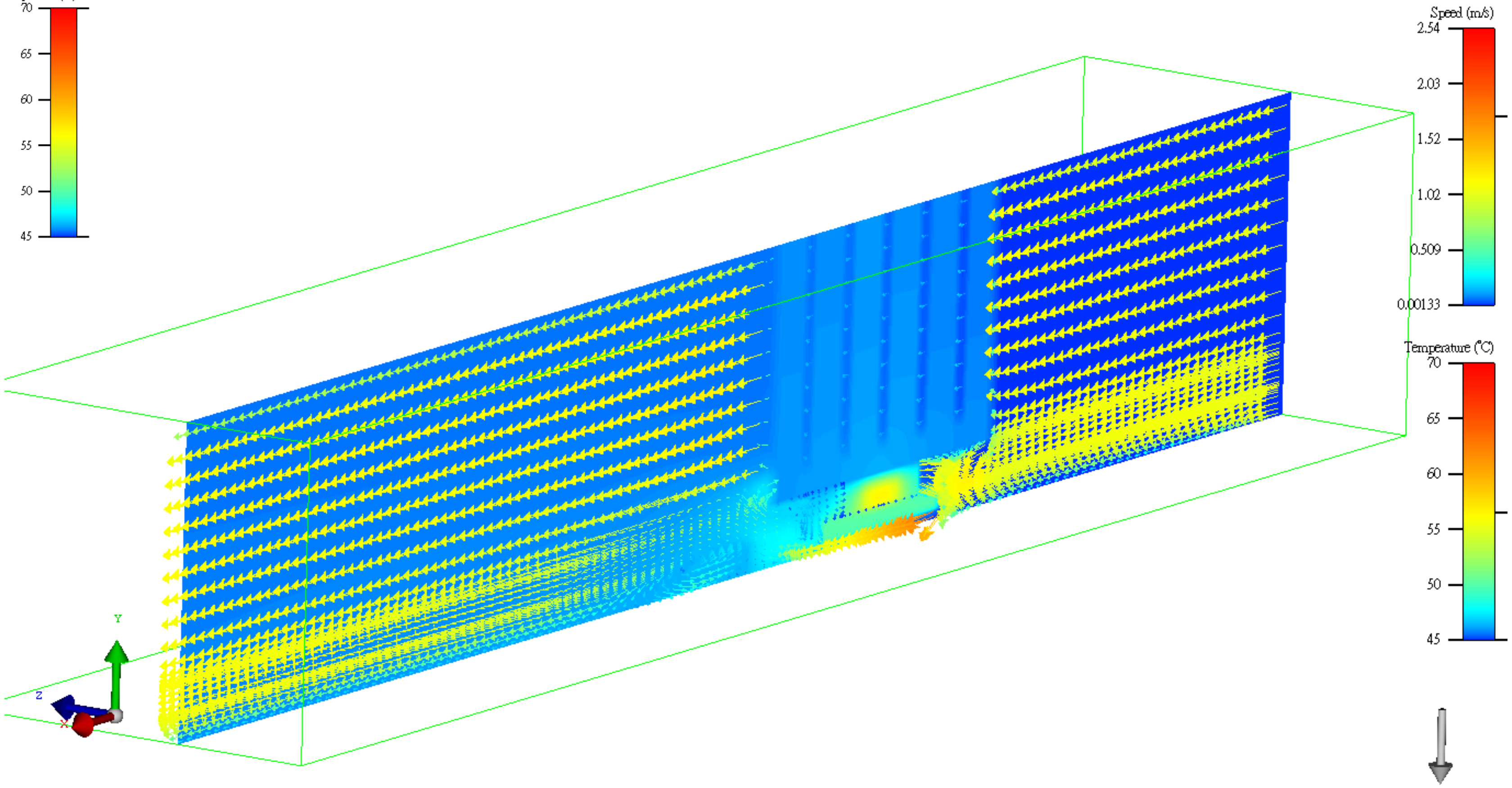
If airflow is fixed (e.g., 200 LFM) and space is sufficient,
a heat sink with base area ~4x the heat source is selected to enhance lateral heat spreading.



I initially selected the MD60-30B. FloTHERM simulation predicted a junction temperature of 70.2°C. The effective thermal resistance (including the mold and air gap path) was higher than expected, which will be discussed in the analysis section. I then iterated the design and selected the **MD60-40B**, which reduced **Tj to 69.8°C**, meeting the specification.

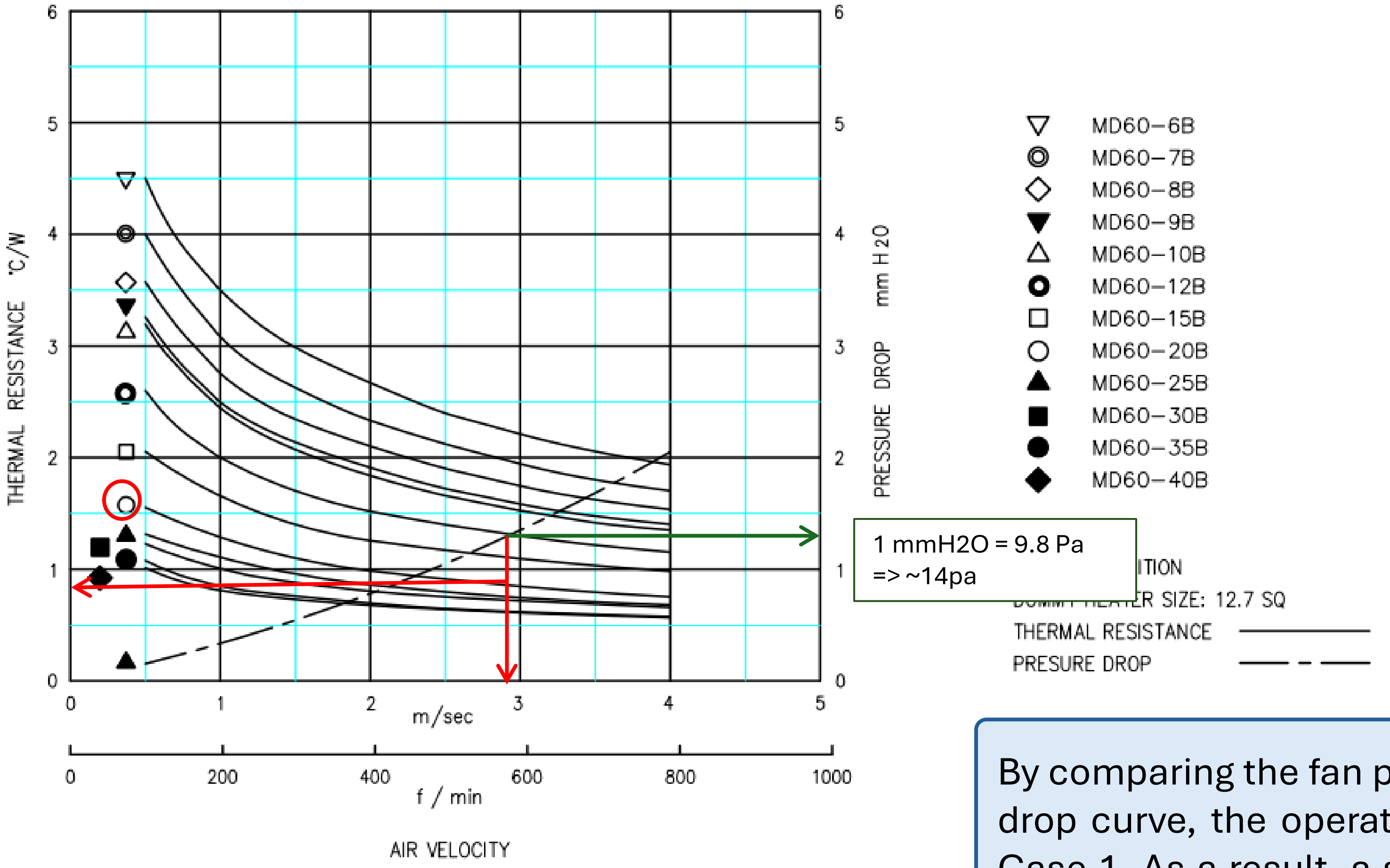
Case 1 — Temperature and Velocity Distributions

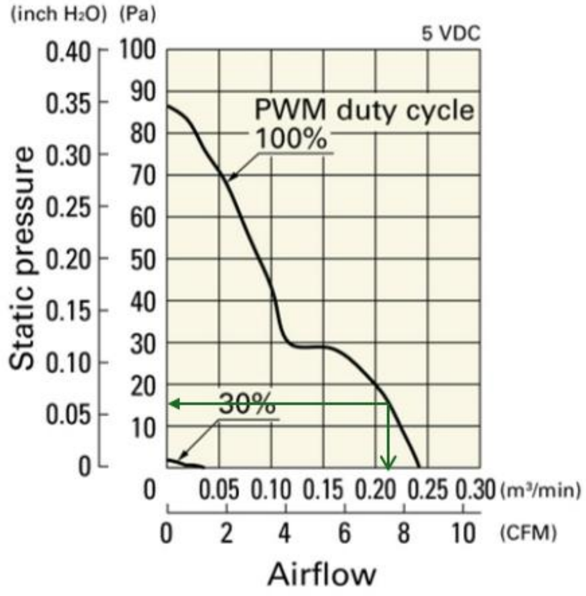




Case 2 — Fan Given (Fan Curve Known)

If the fan is pre-selected, the operating airflow is determined by the intersection of the fan curve and the system pressure drop curve.

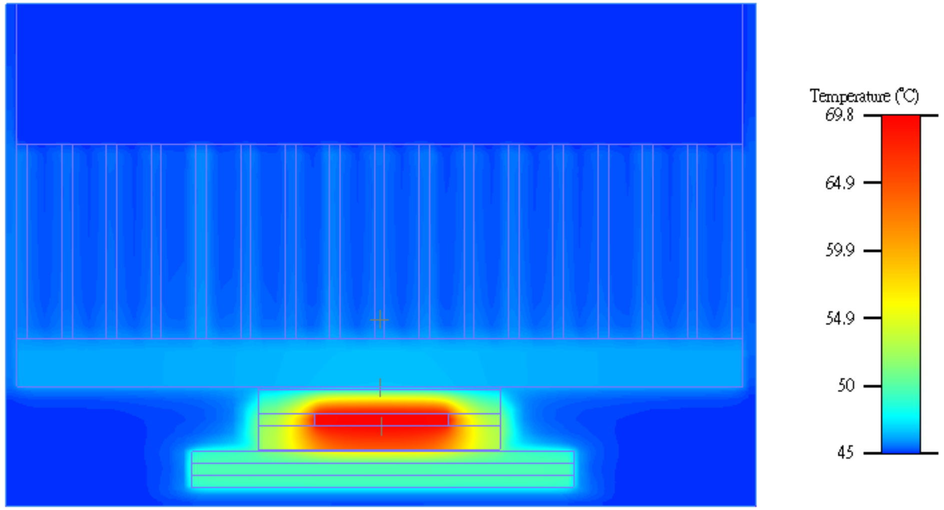


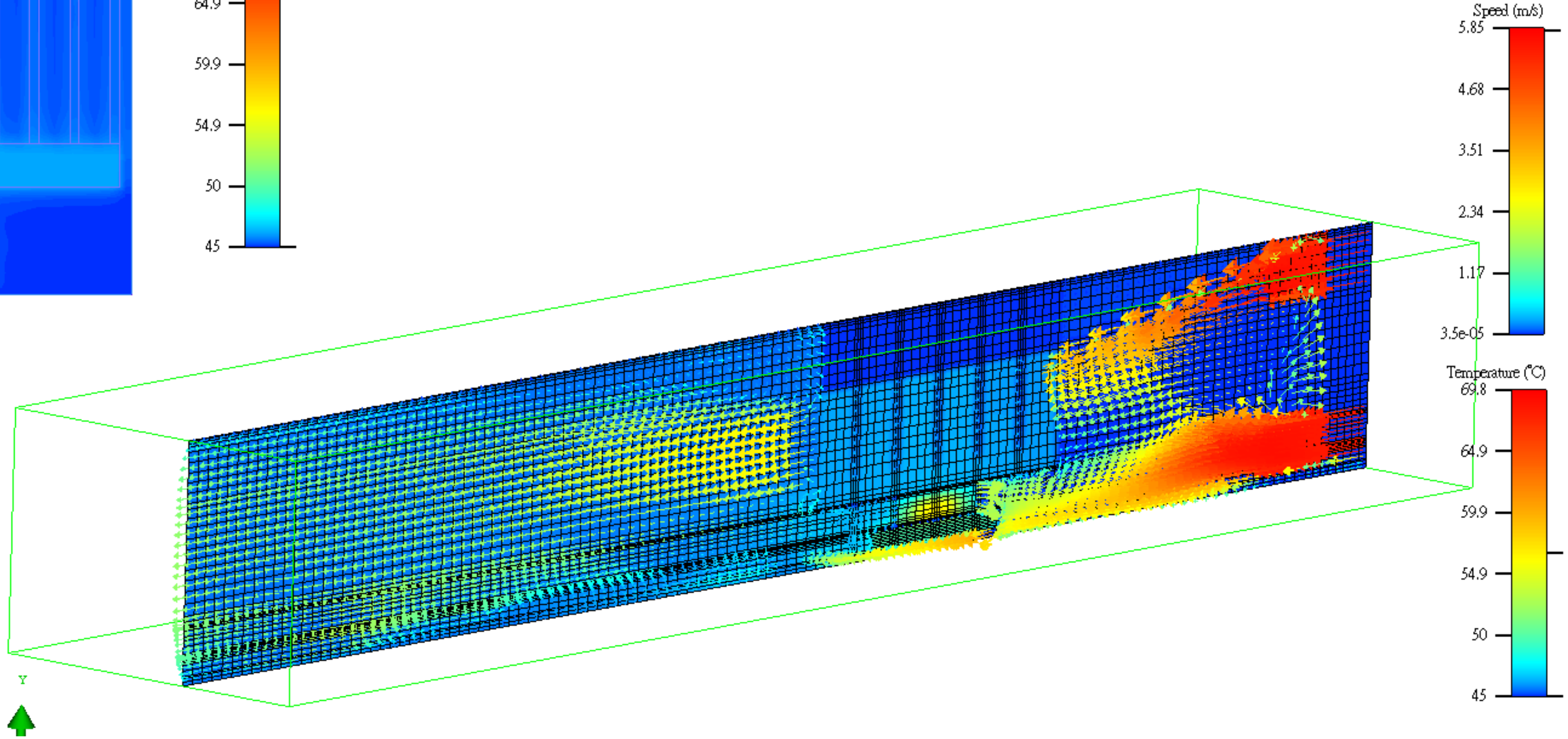


*Estimated airflow ≈ 7.5 CFM based on approach velocity and effective flow area

By comparing the fan performance curve with the system pressure drop curve, the operating point indicates a higher airflow than in Case 1. As a result, a smaller heatsink (**MD60-20B**) was selected. The resulting junction temperature is **Tj = 69.8˚C.**

Case 2 — Temperature and Velocity Distributions





Results and Discussion

	Tj (˚C)	Heat Split (Convected through HSK)	TIM Effective R (K/W)	HSK Effective R (K/W)	Package Mold Effective R (K/W)	PWB Effective R (K/W)	Board to Amb Effective R (K/W)	Contact Effective R (K/W)	Die Effective R (K/W)
Hand calculation	68	100% (conservative assumption)	0.3333	1	10	6.663	10	9.62	0.083
Flotherm Fixed Flow (HSK: MD60-30B)	70.2	74%	0.307	0.991	15.73	6.65	10.67	15.36	0
Flotherm Fixed Flow (HSK: MD60-40B)	69.8	74%	0.37	0.838	15.43	6.8	10.88	15.34	0
Flotherm DC Fan (HSK: MD60-20B)	69.6	74%	0.313	0.986	15.4	6.75	11.08	14.2	0

1. The effective thermal resistance (including the mold and air-gap path) was higher than expected due to oversimplification of the effective area in the hand calculation. The **hand calculation neglects the spreading resistance** from the package footprint into the larger PWB, leading to an underestimation of the package-to-board thermal resistance.
2. The **mold and contact resistance dominate the overall thermal resistance** in the current design. Potential improvements include selecting higher-thermal-conductivity materials, reducing package thickness, and filling the air gap with thermally conductive materials to improve heat transfer.

Backup - Example

EXAMPLE 6.9

Consider the chip package with heat sink shown in Figure 6.13. The thermal resistance of the heat sink is obtained from a vendor catalog and is specified as 1.0 K/W. The silicon die is 1 cm × 1 cm and is 1 mm thick. The overall package size is 2 cm × 2 cm. The package is 5 mm thick and the mold material has a thermal conductivity of 0.8 W/mK. The package dissipates 2 W. The thermal interface material is 0.2 mm thick and has a thermal conductivity of 1.5 W/mK. The air gap between the package and the printed wiring board is expected to be 0.1 mm thick. The board has a construction similar to that described in Example 6.7. Thermal conduction through the leads is assumed to be negligible. Ambient air temperature is 45°C. Compute the value of the die temperature, if the thermal resistance from the PWB to the air is known to equal 10 K/W.

Solution

In order to solve this problem, we can employ the resistance network shown in Figure 6.14b. Some of the thermal resistances like R_{sa} and R_{4a} have been specified in the problem. A first order estimation of the other resistances can be made in the following manner:

$$R_{j1} = \left.\frac{L}{kA}\right|_{\text{silicon}} = \frac{0.001}{120 \times 0.01 \times 0.01} = 0.08333 \text{ K/W}$$

In order to estimate the thermal resistances R_{12} and R_{jb} due to heat conduction in the mold compound, we need to know the surface area over which the heat flow occurs. Intuitively, it is apparent the heat would flow out of the die and spread in the mold compound. The mean of the die and package areas can be used to obtain a good first estimate of the conduction resistance in the mold compound. Additionally, we can assume that the die is located exactly at the center of the package. Thus, the thickness of the mold compound on either side of the die is (5 mm − 1 mm)/2 = 2 mm. Now we can compute the resistances R_{12} and R_{jb} as follows:

$$R_{12} = R_{jb} = \left.\frac{L}{kA}\right|_{\text{mold}} = \frac{0.002}{0.8 \times ((0.02^2 + 0.01^2)/2)} = 10 \text{ K/W}$$

The thermal resistance in the grease layer, which is spread out on the entire package surface, can be estimated as follows:

$$R_{2s} = \left.\frac{L}{kA}\right|_{\text{grease}} = \frac{0.0002}{1.5 \times 0.02 \times 0.02} = 0.3333 \text{ K/W}$$

Using the air thermal conductivity of 0.026 W/mK, the thermal resistance in the air gap can be estimated as follows:

$$R_{b3} = \left.\frac{L}{kA}\right|_{\text{air}} = \frac{0.0001}{0.026 \times 0.02 \times 0.02} = 9.62 \text{ K/W}$$

The thermal resistance of the motherboard can be obtained from the solution to Example 6.7 and can be written as:

$$R_{34} = R_1 + R_2 + R_3 = 3.33 + 0.0026 + 3.33 = 6.663 \text{ K/W}$$

Using the laws of series resistances discussed earlier, the resistance network in Figure 6.14 can be replaced by a simpler representation as shown below:

Thus,

$$R_{ja1} = R_{jb} + R_{b3} + R_{34} + R_{4a} = 10 + 9.62 + 6.66 + 10 = 36.3 \text{ K/W}$$

$$R_{ja2} = R_{j1} + R_{12} + R_{2s} + R_{sa} = 0.0833 + 10 + 0.333 + 1 = 11.4 \text{ K/W}$$

Now resistances R_{ja1} and R_{ja2} are in parallel since the end point temperatures are identical. The equivalent resistance, R_{equiv}, between the junction and the ambient is:

$$\frac{1}{R_{\text{equiv}}} = \frac{1}{36.3} + \frac{1}{11.4} = 0.11$$

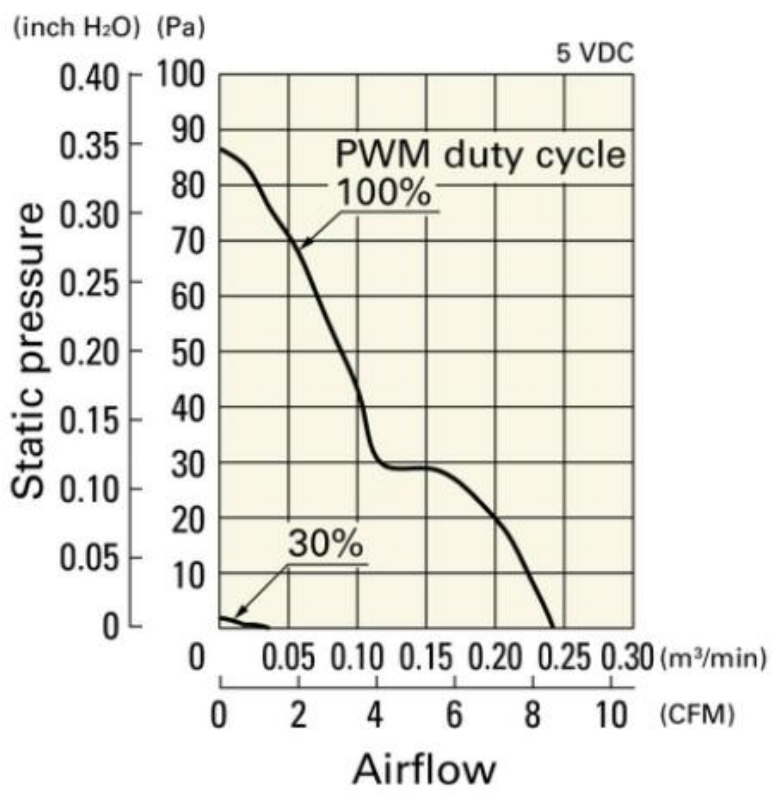
$$R_{\text{equiv}} = 8.7 \text{ K/W}$$

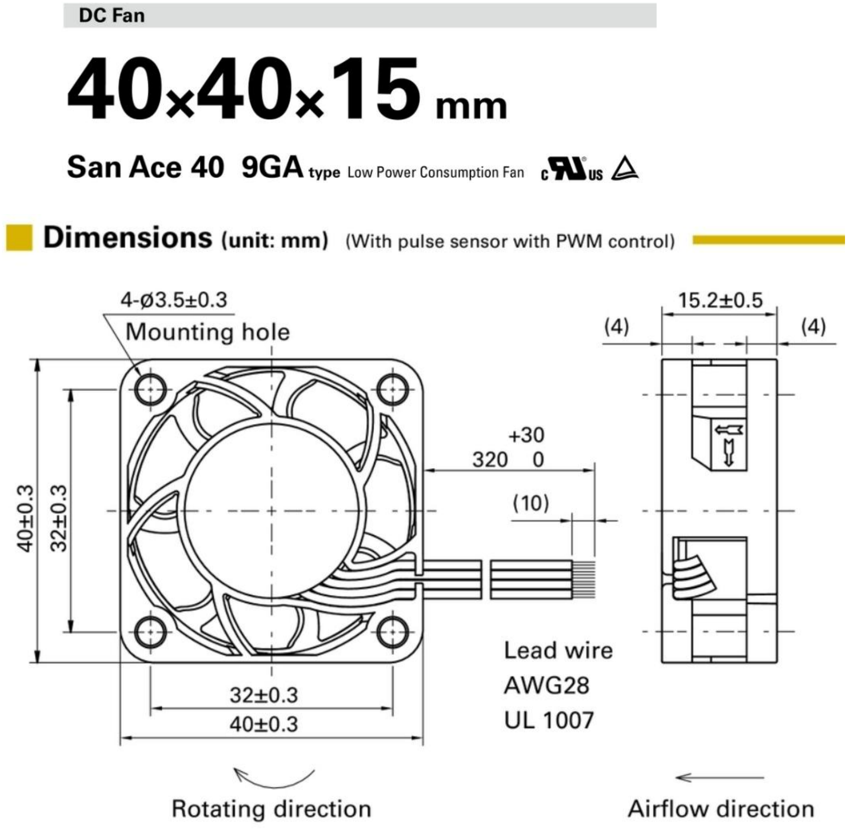
$$T_j = qR_{\text{equiv}} + T_a$$

$$= (2)(8.7) + 45 = 62.3°\text{C}$$

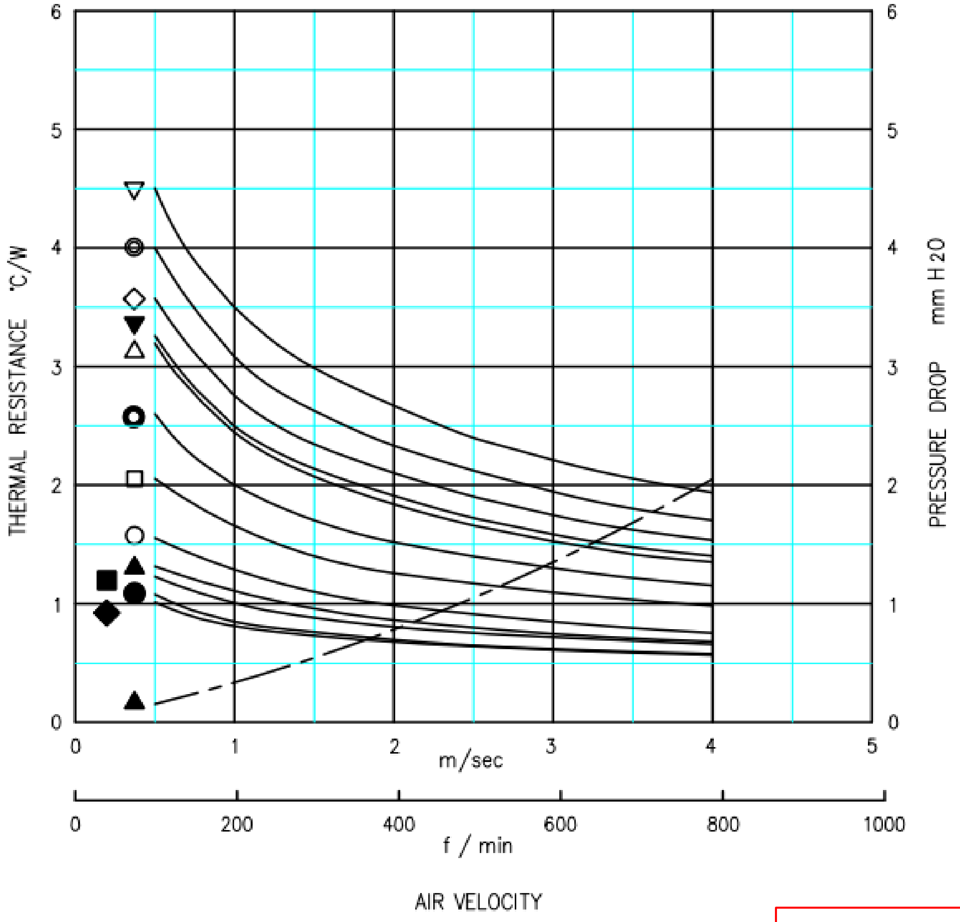
Backup - Fan

PWM duty cycle





Backup – Heat Sink

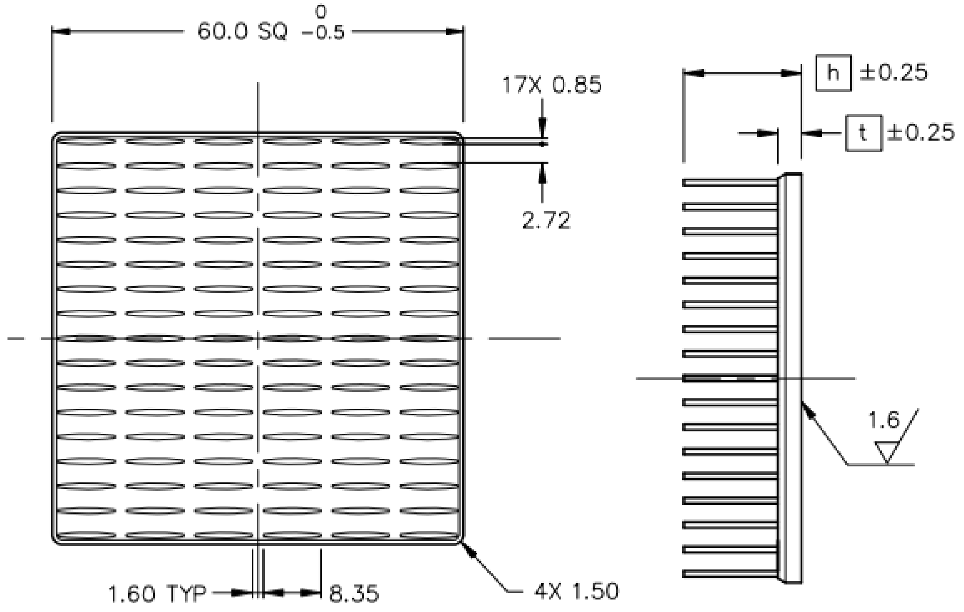


1 mmH2O = 9.8 Pa

- ▽ MD60−6B
- ◎ MD60−7B
- ◇ MD60−8B
- ▼ MD60−9B
- △ MD60−10B
- ⊙ MD60−12B
- □ MD60−15B
- ○ MD60−20B
- ▲ MD60−25B
- ■ MD60−30B
- ● MD60−35B
- ◆ MD60−40B

DUCTED CONDITION
DUMMY HEATER SIZE: 12.7 SQ
THERMAL RESISTANCE ———
PRESURE DROP — - —

BASED ON ALPHA'S STANDARD TEST PROCEDURE.
REFER TO TECHNICAL INFORMATION.



MODEL	HEIGHT h	THICKNESS t	WEIGHT (grams)
MD60−6B	6	3.00	33.1
MD60−7B	7		34.9
MD60−8B	8		36.7
MD60−9B	9		38.6
MD60−10B	10	4.00	47.3
MD60−12B	12		50.3
MD60−15B	15		54.7
MD60−20B	20		62.1
MD60−25B	25		69.5
MD60−30B	30		78.6
MD60−35B	35		86.3
MD60−40B	40		94.0
MD60−h B	h ≦ 9	3.00	−
	9 < h ≦ 40	4.00	−